Track B
Electricity Generation – Fuel of Choice?

Natural Gas Technology: Investment in a Healthy U.S. Energy Future

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Electric Power Fuel Choice Considerations

Supply

- Cost / Volatility
- Availability / Reliability
- Characteristics / Emissions

Technology

- Capital / Operating Cost
- Performance Characteristics

Policy

- Regulations
- Incentives

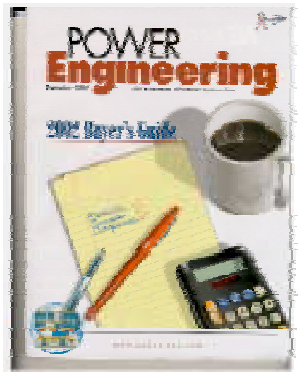
Technology Development - the Key

- **Gas Supply, Infrastructure, Storage**
  - Existing fields
  - Marginal/Unconventional Resources
  - Frontier Resources
  - Increased Market Access
- **Advanced Power Systems**
  - Fuel Cells
  - Turbines
  - Hybrids
  - Vision 21

High Efficiency Engines and Turbines Program "HEET"

Building on Success of ATS

General Electric 7H (ATS)
400 MW, 60% Efficiency



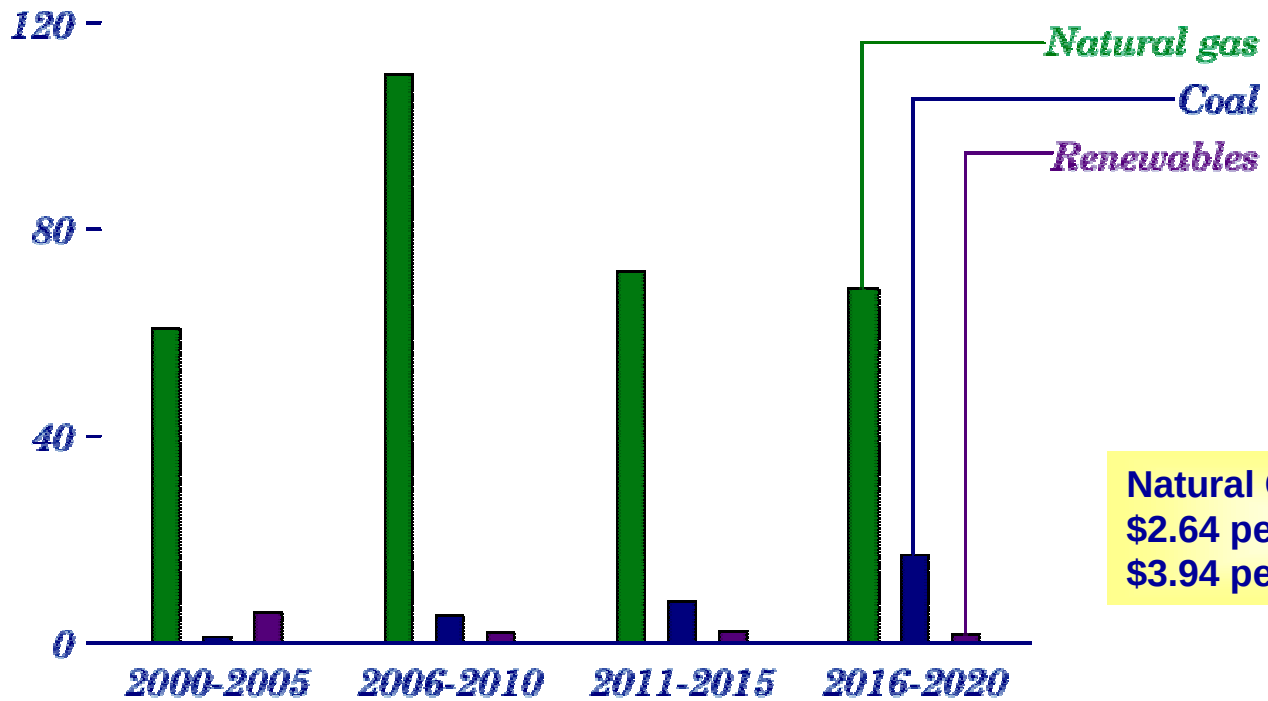
Projects of the Year 2001
Editors Choice Award

Bright Lights Award
2000

Siemens - Westinghouse 501GS
375 MW, 59% Efficiency

Generating Capacity Additions by Fuel Type (gigawatts)

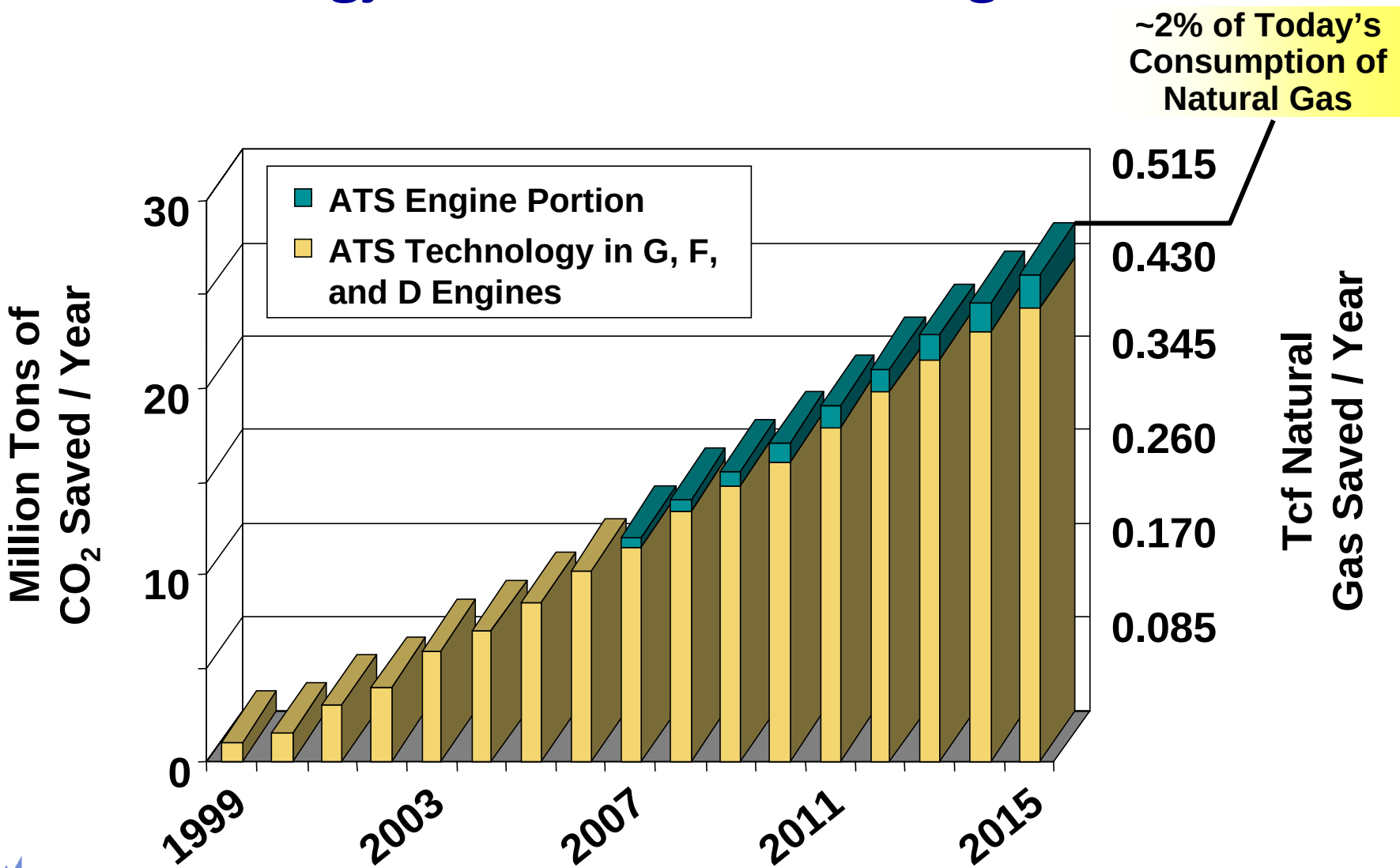
Total: 355 GWe
88% CT or CC



Natural Gas Prices:
$2.64 per MCF in 2002
$3.94 per MCF in 2020

DOE-EIA Annual Energy Outlook, 2002

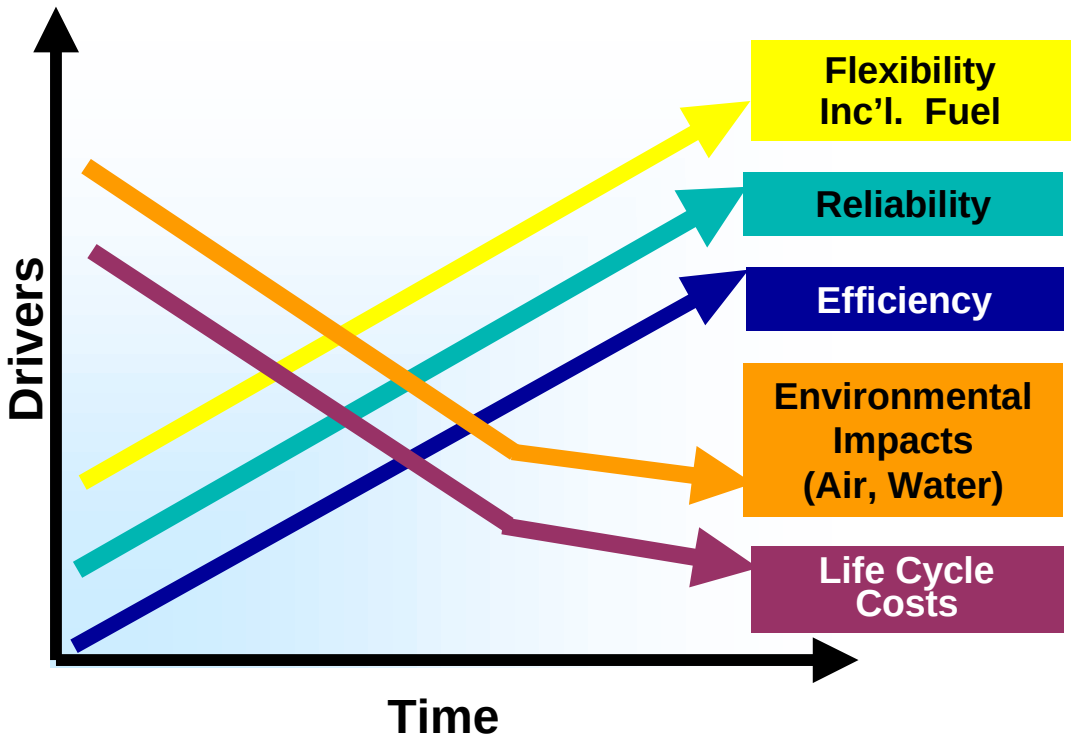
Technology Infusion Into Existing Products



Siemens Westinghouse Power Corp. ã, August 2001

HEET Program

Goals/Objectives



Technology Roadmaps

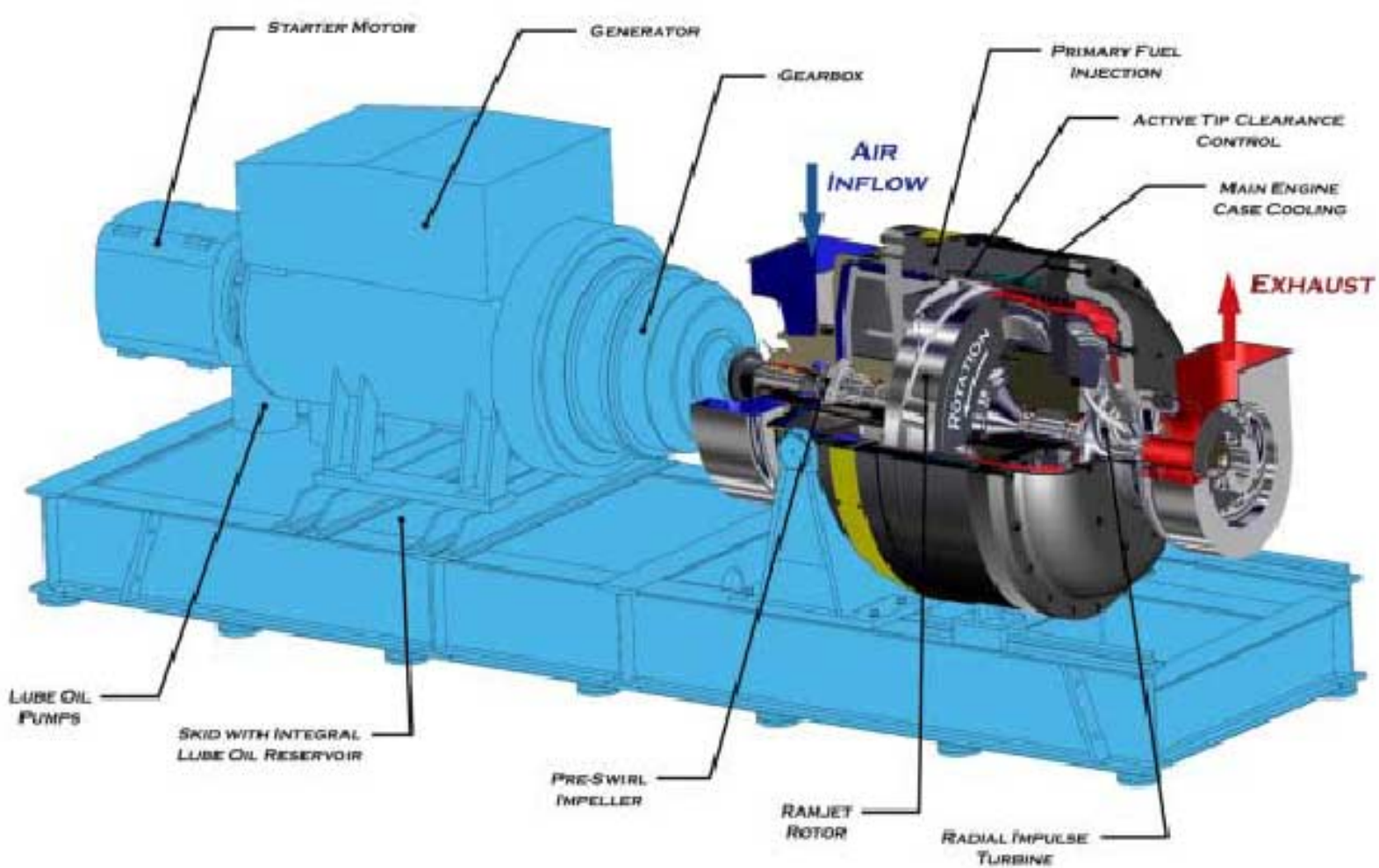
- Materials
- Combustion / Emission Reduction
- Aero / Thermal
- Instrumentation / Controls & Sensors
- Design Tools

Distributed Generation: Options for the Future

- Customer choice
- Siting flexibility
- Opportunity fuels
  - Biomass, landfill gas, anerobic digester gas

- Less capital investment risk
- Efficient, reliable, secure, environmentally benign
- Elimination of transmission and distribution investment requirements and line loss problems

Ramgen 2.8 MWe Generator



Source: Ramgen Corp.

Fuel Cells and Hybrids

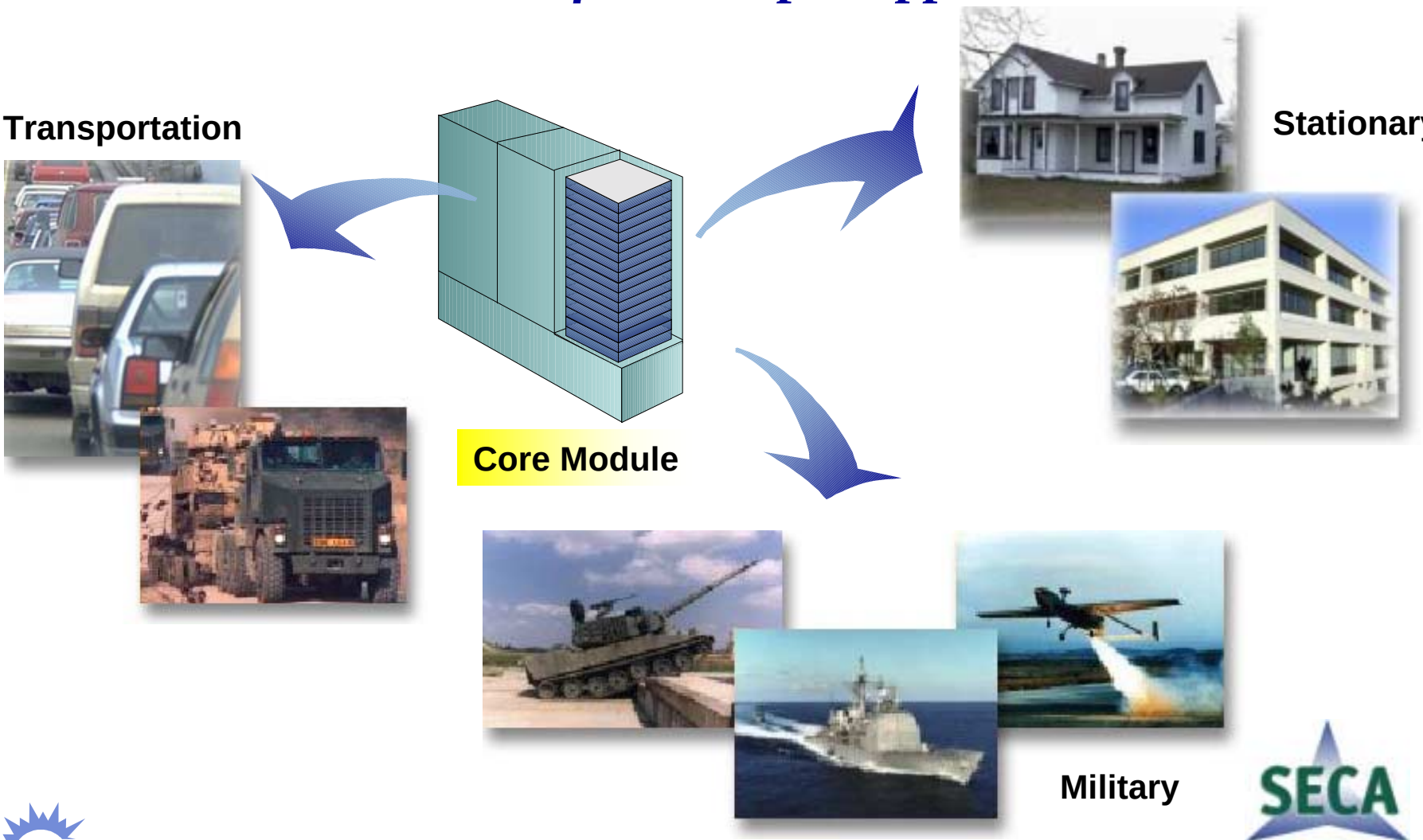
Fuel Cell Technology Potential

- **Order-of-magnitude potential:**
  - Order-of-magnitude reduction in cost expected
  - Near factor of two improvement in efficiency through hybridization

- **How:**
  - Breakthroughs in ceramic materials
  - Design innovations leading to high power densities
  - Compact fuel processing and thermal integration
  - Incorporation of semiconductor industry manufacturing techniques
  - Improvements in power electronics
- **Result: Deeper penetration, wider application, dramatic cost reduction**

Solid State Energy Conversion Alliance

Core Module for Multiple Applications



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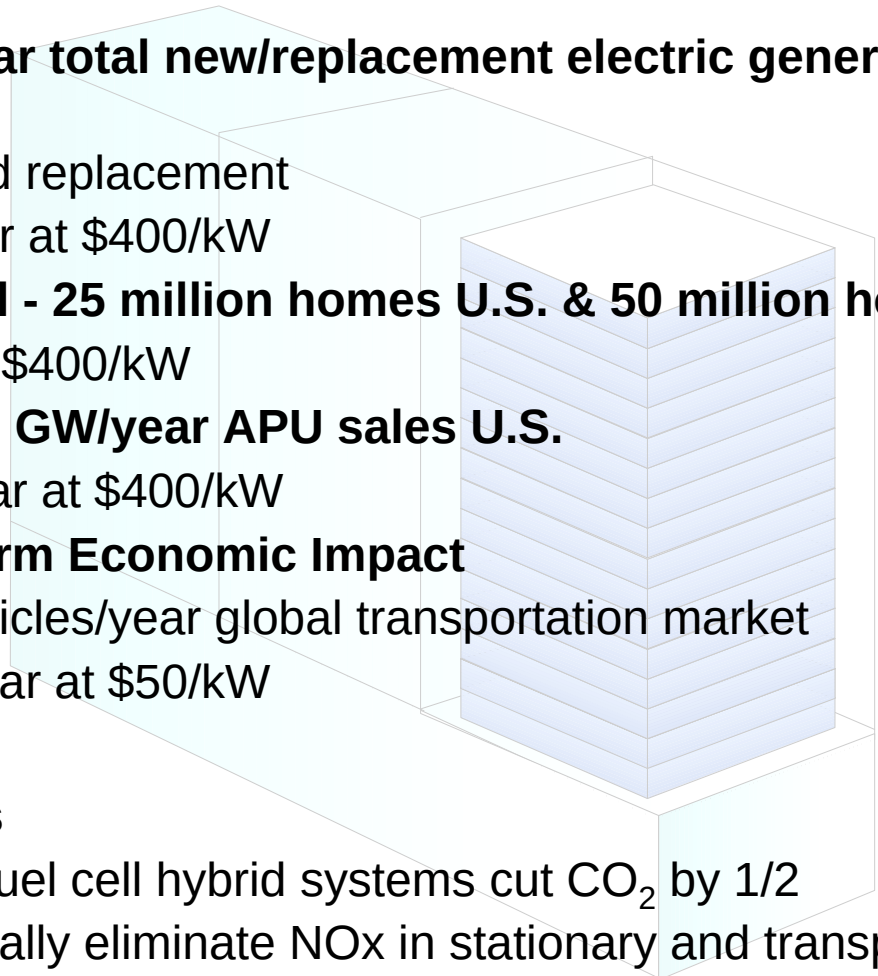
Strategic Center for Natural Gas

Public Economic and Environmental Benefits

Economic

- **Nearly 80 GW/year total new/replacement electric generation global market by 2010**
  - 2% growth and replacement
  - $32 billion/year at $400/kW
- **Sales Residential - 25 million homes U.S. & 50 million homes Europe**
  - $150 billion at $400/kW
- **Potential Truck 2 GW/year APU sales U.S.**
  - $0.8 billion/year at $400/kW
- **Ultimate Long-term Economic Impact**
  - 55 million vehicles/year global transportation market
  - $200 billion/year at $50/kW



Environmental

- **Lower emissions**
  - 60% efficient fuel cell hybrid systems cut CO_2 by 1/2
  - Fuel cells virtually eliminate NOx in stationary and transportation applications

SECA Goals and Applications

2005

- **$800/kW**
  - Long-haul trucks
  - RVs
  - Military
  - Premium power

2010

- **$400/kW**
  - Residential & industrial CHP
  - Transportation auxiliary power

2015

- **Vision 21 power plants**
  - 75% efficient
- **Hybrid systems**
  - 60–70% efficient

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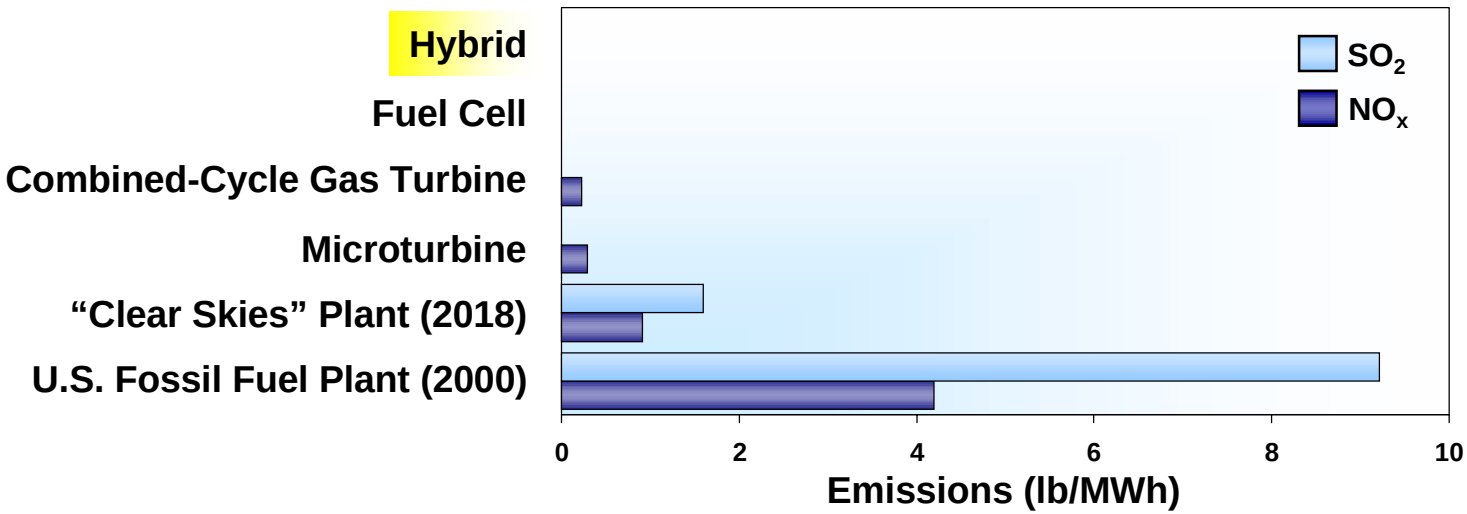
SECA Players / Efforts

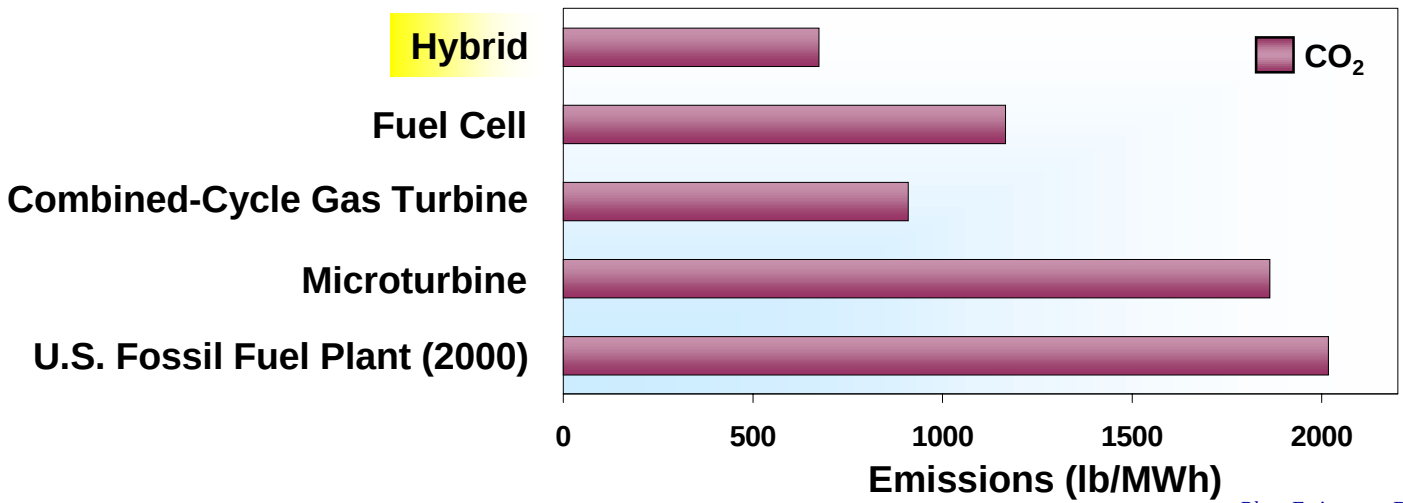
Universities, National Labs, Industry

Hybrids: Results from Five 1998 PRDA Studies

- Electrical efficiencies of >70% are possible
- Systems with efficiencies of about 65% produce much lower cost of electricity
- Initial program should start with sizes significantly less than 20 MW
- Off-the-shelf turbines poor fit for large-scale hybrid systems

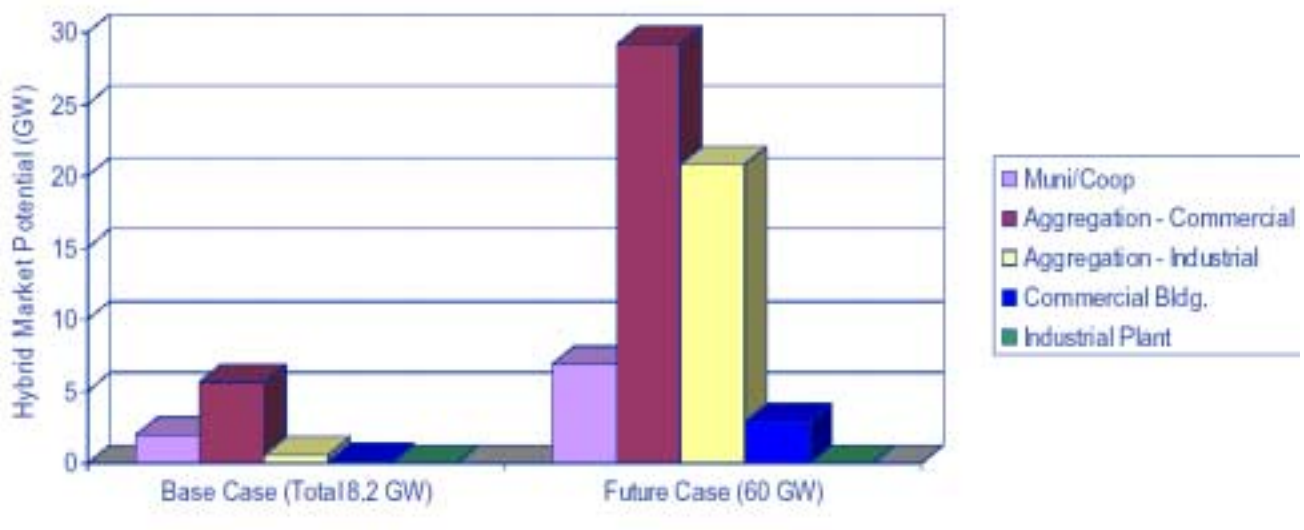
Hybrid Efficiency Leads to Low Emissions





Plant Estimates: D. Smith, NETL
Hybrid Estimates: L. Berkshire, NETL
Other Technology Estimates: S. O'Brien, UTC Fuel Cells

Market Potential for Hybrid Systems



- **Current (2005) hybrids can capture 8.2 GW of market share on COE basis in 15 – 25 MW size**
- **Future (2010+) hybrid system can potentially capture 60 GW of market share**
- **DOE's Industries of the Future identified "addressable hybrid market" of 70 GW by 2010 in 0.25 – 20 MW size**

Source: Resource Dynamics, Oct 2001

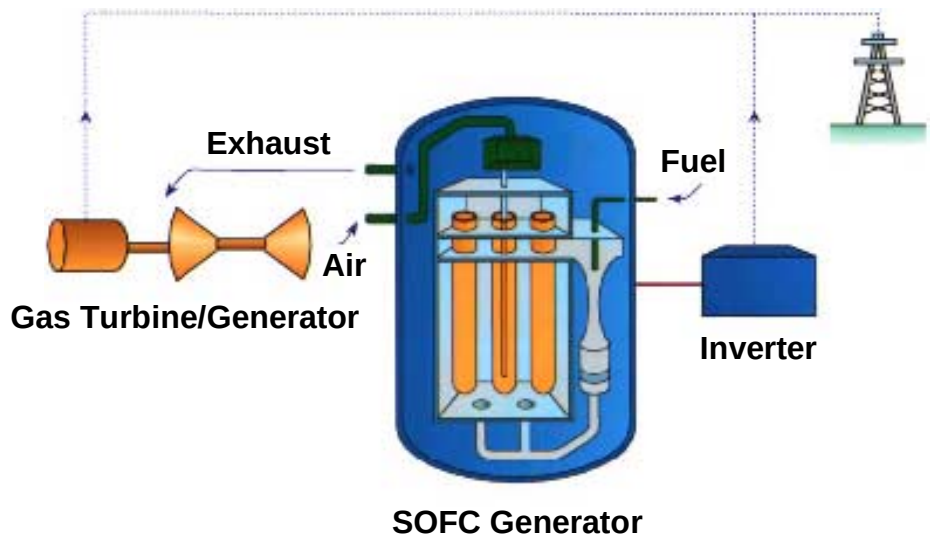
Current Hybrid Projects

- National Fuel Cell Research Center
- Rolls-Royce
- Siemens Westinghouse Power Corporation
- Fuel Cell Energy
- Honeywell International

Siemens Westinghouse

Solid Oxide Fuel Cell / Gas Turbine

- World's first combined-cycle SOFC / GT
- 200 kW proof-of-concept demonstration
- Operated > 1,000 hours
- Located at and operated by NFCRC
- 300 and 550 kW demos planned



FuelCell Energy

Direct Fuel Cell / Turbine Sub-Megawatt Hybrid System

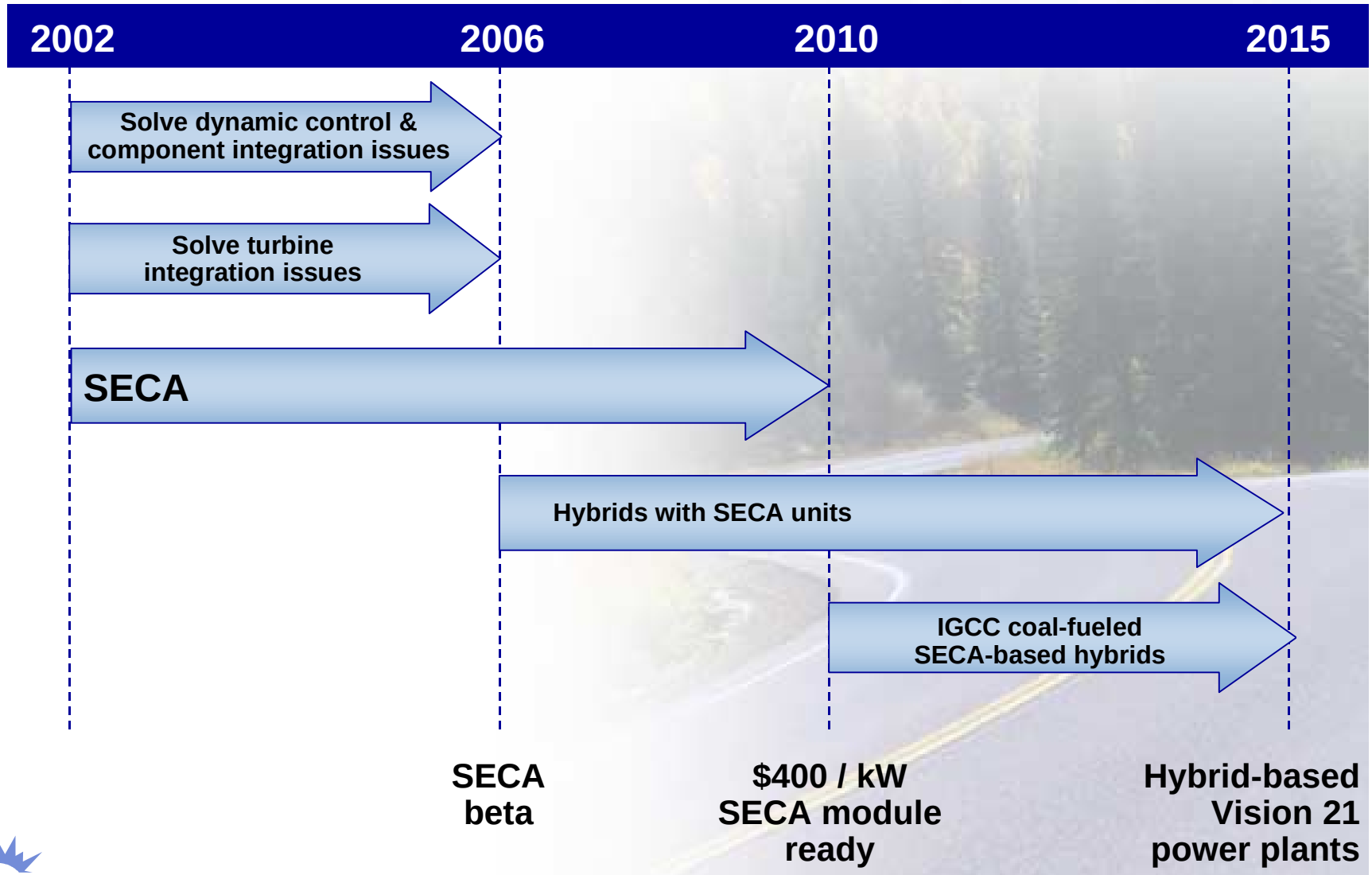
- **First demonstration of indirect fuel cell turbine hybrid system based on MCFC technology**
- **Completed 4,700 hours testing with electrical efficiency of 52%**
- **Conceptual and engineering design of 40-MW hybrid DFC/T hybrid power plant**

Honeywell International

SECA-Based Fuel Cell Hybrid

- **Planar SOFC and direct-fired turbine**
- **Estimated efficiency 67%**
- **System net power 475 kW**
- **First SECA-based hybrid**

Technology Road Map for Hybrid Power Systems



Vision 21
Ultra-Clean Energy Plant of Future

Energy Plants for Post-2015

- **Use available feeds**
  - Coal, gas, biomass, waste
- **Electricity primary product**
  - May co-produce fuels, chemicals, steam, heat

Goal

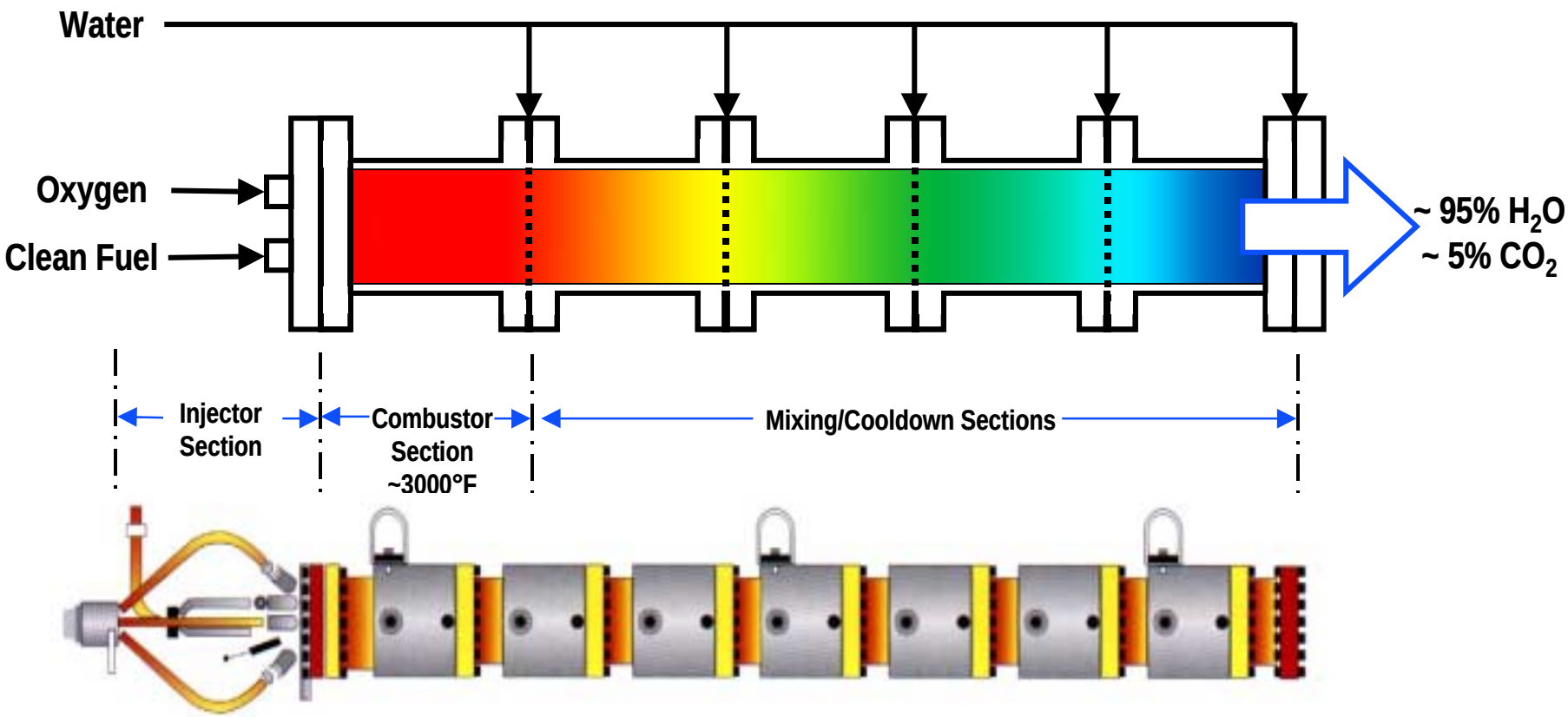
Absolutely Minimize Environmental Implications of Fossil Energy Use

Approach

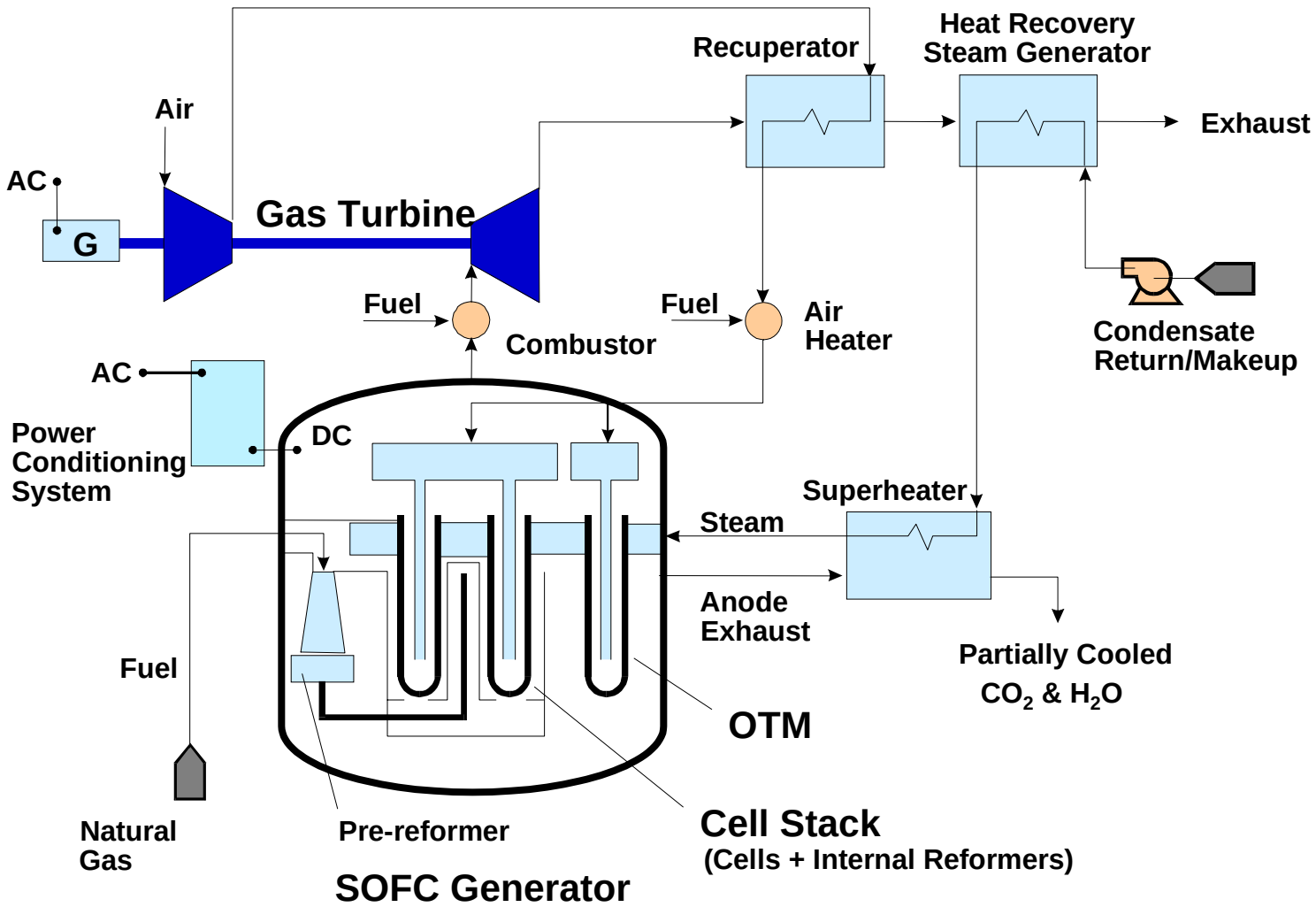
- **Maximize efficiency**
  - 75% gas-to-electric
  - 60% coal-to-electric
- **Near-zero emissions**
  - Option for carbon sequestration

The Clean Energy Systems Gas Generator

- **Typical Operating Ranges**
  - 1200 to 3200° F
  - 1200 to 3200 psia



Siemens Westinghouse - Praxair Zero Emission Power System



Source: Siemens Westinghouse Power Corp.

A Vision for 2015

Putting the Pieces Together

SECA

SECA-Based Fuel Cells

Vision 21 Power Plants

Carbon Sequestration

Gasification with Cleanup & Separation

Optimized Turbines

System Integration

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www.netl.doe.gov/scng